DEVRELER ve SİSTEMLER

BIMU2058 – CSBM2092

Yrd. Doç. Dr. Fatih KELEŞ

İÇERİK

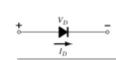
- Yarıiletkenler
- Diyotlar
- Diyot Uygulamaları

Semiconductors and diodes

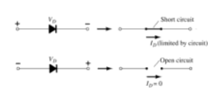
- Ideal diodes
- Electrical properties of solids
- Semiconductors
- *pn* Junctions

Ideal Diodes

The diode is a 2-terminal device.

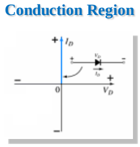


A diode <u>ideally</u> conducts in only one direction.



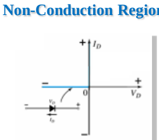
Ideal Diode Characteristics

Conduction Region



- The voltage across the diode is 0 V
- The current is infinite
- The forward resistance is defined as $R_F = V_F / I_F$
- The diode acts like a short

Non-Conduction Region



- All of the voltage is across the diode
- The current is 0 A
- The reverse resistance is defined as $R_R = V_R / I_R$
- The diode acts like open

Electrical properties of solids

- **Conductors**
  - e.g. copper or aluminium
  - have a cloud of free electrons (at all temperatures above absolute zero). If an electric field is applied electrons will flow causing an electric current.
- **Insulators**
  - e.g. polythene
  - electrons are tightly bound to atoms, so, only a few can break free to conduct electricity.

Properties of solids…

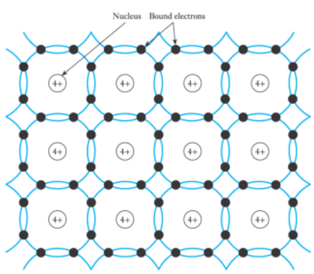
- Semiconductors
  - e.g. silicon or germanium
  - at very low temperatures these have the properties of insulators
  - as the material warms up some electrons break free and can move about, and it takes on the properties of a conductor – albeit a poor one
  - however, semiconductors have several properties that make them distinct from conductors and insulators.

Semiconductors

- Pure semiconductors
  - thermal vibration results in some bonds being broken, generating **free electrons** which move about
  - these leave behind **holes** which accept electrons from adjacent atoms and therefore, also move about
  - electrons are **negative charge carriers**
  - holes are **positive charge carriers.**
- At room temperatures there are few charge carriers
  - *pure* semiconductors are poor conductors
  - this is **intrinsic conduction.**

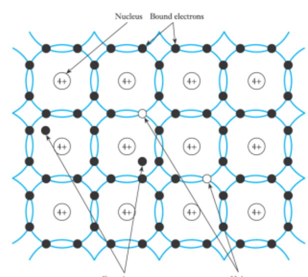
Structure of a semiconductor

- The atomic structure of silicon



Structure of a semiconductor

- The effect of thermal vibration on the structure of silicon



Semiconductor Materials

Materials commonly used in the development of semiconductor devices:

- **Silicon (Si)**
- **Germanium (Ge)**
- **Gallium Arsenide (GaAs)**

Doping

The electrical characteristics of silicon and germanium are improved by adding materials in a process called doping.

There are just two types of doped semiconductor materials:

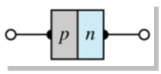
***n*-type**
***p*-type**

- ***n*-type materials contain an excess of conduction band electrons.**
- ***p*-type materials contain an excess of valence band holes.**

p–n Junctions

One end of a silicon or germanium crystal can be doped as a *p*-type material and the other end as an *n*-type material.

The result is a *p-n* junction.

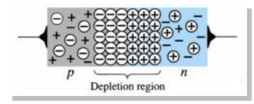


p–n Junctions

At the *p-n* junction, the excess conduction-band electrons on the *n*-type side are attracted to the valence-band holes on the *p*-type side.

The electrons in the *n*-type material migrate across the junction to the *p*-type material (electron flow).

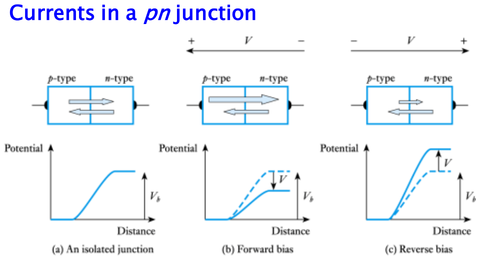
The electron migration results in a negative charge on the p-type side of the junction and a positive charge on the n-type side of the junction.



The result is the formation of a depletion region around the junction.

pn Junctions

- Currents in a *pn* junction



pn Junctions

- Forward and reverse currents
  - *pn* junction current is given approximately by

$$I = I_S\left(\exp\frac{eV}{\eta kT} - 1\right)$$

  - where I is the current, e is the electronic charge, V is the applied voltage, k is Boltzmann's constant, T is the absolute temperature and η (Greek letter *eta*) is a constant in the range 1 to 2 determined by the junction material
  - for most purposes we can assume $\eta = 1$.

pn Junctions

- Thus,

$$I \approx I_S\left(\exp\frac{eV}{kT} - 1\right)$$

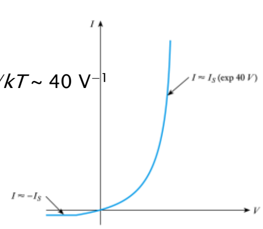
at room temperature $e/kT \sim 40\ \mathrm{V}^{-1}$

- If $V > +0.1$ V,

$$I \approx I_s\left(\exp\frac{eV}{kT}\right) = I_s(\exp 40V)$$

- If $V < -0.1$ V,

$$I \approx I_s(0-1) = -I_s$$



I_S is the reverse saturation current.

Diode Operating Conditions

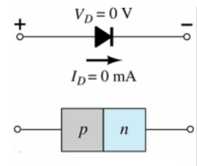
A diode has three operating conditions:

- No bias
- Forward bias
- Reverse bias

Diode Operating Conditions

No Bias

- No external voltage is applied: $V_D = 0$ V
- No current is flowing: $I_D = 0$ A
- Only a modest depletion region exists



Majority and Minority Carriers

Two currents through a diode:

Majority Carriers

- The majority carriers in *n*-type materials are electrons.
- The majority carriers in *p*-type materials are holes.

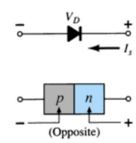
Minority Carriers

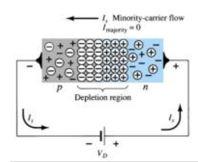
- The minority carriers in *n*-type materials are holes.
- The minority carriers in *p*-type materials are electrons.

Diode Operating Conditions

Reverse Bias

External voltage is applied across the *p-n* junction in the opposite polarity of the *p*- and *n*-type materials.



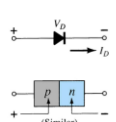


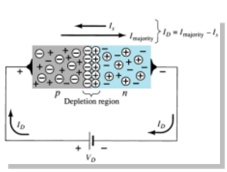
- The reverse voltage causes the depletion region to widen.
- The electrons in the *n*-type material are attracted toward the positive terminal of the voltage source.
- The holes in the *p*-type material are attracted toward the negative terminal of the voltage source.

Diode Operating Conditions

Forward Bias

External voltage is applied across the *p-n* junction in the same polarity as the *p*- and *n*-type materials.



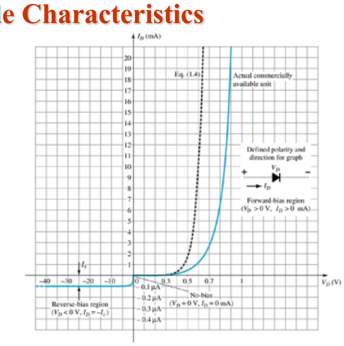


- The forward voltage causes the depletion region to narrow.
- The electrons and holes are pushed toward the *p-n* junction.
- The electrons and holes have sufficient energy to cross the *p-n* junction.

Actual Diode Characteristics

Note the regions for no bias, reverse bias, and forward bias conditions.

Carefully note the scale for each of these conditions.

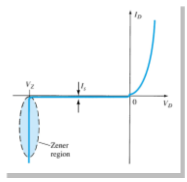


Zener Region

The Zener region is in the diode’s reverse-bias region.

At some point the reverse bias voltage is so large the diode breaks down and the reverse current increases dramatically.

- The maximum reverse voltage that won’t take a diode into the zener region is called the **peak inverse voltage** or **peak reverse voltage**.
- The voltage that causes a diode to enter the zener region of operation is called the **zener voltage (V_Z)**.



Forward Bias Voltage

The point at which the diode changes from no-bias condition to forward-bias condition occurs when the electrons and holes are given sufficient energy to cross the *p-n* junction. This energy comes from the external voltage applied across the diode.

The forward bias voltage required for a:

- gallium arsenide diode ≅ 1.2 V
- silicon diode ≅ 0.7 V
- germanium diode ≅ 0.3 V

Temperature Effects

As temperature increases it adds energy to the diode.

- It reduces the required forward bias voltage for forward-bias conduction.
- It increases the amount of reverse current in the reverse-bias condition.

Germanium diodes are more sensitive to temperature variations than silicon or gallium arsenide diodes.

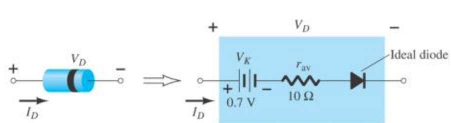
Resistance Levels

Semiconductors react differently to DC and AC currents.

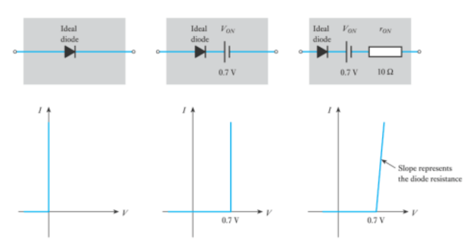
There are three types of resistance:

- DC (static) resistance
- AC (dynamic) resistance
- Average AC resistance

Diode Equivalent Circuit



Diode Equivalent Circuit

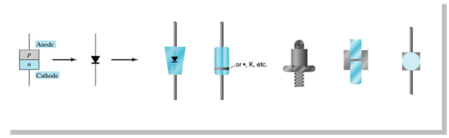


Diode Specification Sheets

Data about a diode is presented uniformly for many different diodes. This makes cross-matching of diodes for replacement or design easier.

1. Forward Voltage (V_F) at a specified current and temperature
2. Maximum forward current (I_F) at a specified temperature
3. Reverse saturation current (I_R) at a specified voltage and temperature
4. Reverse voltage rating, PIV or PRV or V(BR), at a specified temperature
5. Maximum power dissipation at a specified temperature
6. Capacitance levels
7. Operating temperature range

Diode Symbol and Packaging



The anode is abbreviated A
The cathode is abbreviated K

Diode Testing

Diode checker
Ohmmeter
Curve tracer

Diode Checker

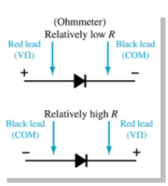
Many digital multimeters have a diode checking function. The diode should be tested out of circuit.

A normal diode exhibits its forward voltage:

- Gallium arsenide ≅ 1.2 V
- Silicon diode ≅ 0.7 V
- Germanium diode ≅ 0.3 V

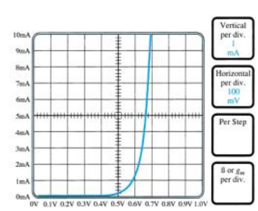
Ohmmeter

An ohmmeter set on a low Ohms scale can be used to test a diode. The diode should be tested out of circuit.



Curve Tracer

A curve tracer displays the characteristic curve of a diode in the test circuit. This curve can be compared to the specifications of the diode from a data sheet.



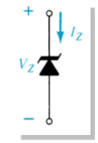
Other Types of Diodes

Zener diode
Light-emitting diode
Diode arrays

Zener Diode

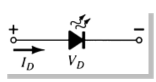
A Zener is a diode operated in reverse bias at the Zener voltage (V_Z).

Common Zener voltages are between 1.8 V and 200 V



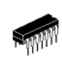
Light-Emitting Diode (LED)

An LED emits photons when it is forward biased.
These can be in the infrared or visible spectrum.
The forward bias voltage is usually in the range of 2 V to 3 V.

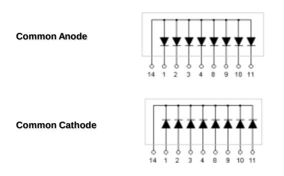


Diode Arrays

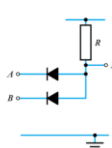
Multiple diodes can be packaged together in an integrated circuit (IC).



A variety of combinations exist.



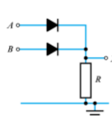
Diode Logic



A	B	X
0	0	0
0	1	0
1	0	0
1	1	1

Logic levels	
In	Out
$V_{IL} = 0$ V $V_{IH} = V_{CC}$	$V_{OL} = V_{Diode} \approx 0.7$ V $V_{OH} = V_{CC}$

(a) AND gate



A	B	X
0	0	0
0	1	1
1	0	1
1	1	1

Logic levels	
In	Out
$V_{IL} = 0$ V $V_{IH} = V_{CC}$	$V_{OL} = 0$ V $V_{OH} = V_{CC} - V_{Diode} = V_{CC} - 0.7$ V

(b) OR gate

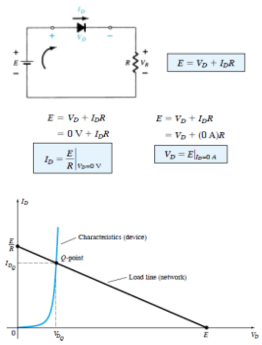
Key points

- Diodes allow current to flow in only one direction.
- At low temperatures semiconductors act like insulators.
- At higher temperatures they begin to conduct.
- Doping of semiconductors leads to the production of *p*-type and *n*-type materials.
- A junction between *p*-type and *n*-type semiconductors has the properties of a diode.
- Silicon semiconductor diodes approximate the behaviour of ideal diodes but have a conduction voltage of about 0.7 V.
- There are also a wide range of special purpose diodes.

Load-Line Analysis

The load line plots all possible combinations of diode current (I_D) and voltage (V_D) for a given circuit. The maximum I_D equals E/R, and the maximum V_D equals E.

The point where the load line and the characteristic curve intersect is the Q-point, which identifies I_D and V_D for a particular diode in a given circuit.



54

Series Diode Configurations

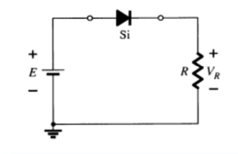
Forward Bias

Constants

- Silicon Diode: V_D = 0.7 V
- Germanium Diode: V_D = 0.3 V

Analysis (for silicon)

- V_D = 0.7 V (or $V_D = E$ if $E < 0.7$ V)
- $V_R = E - V_D$
- $I_D = I_R = V_R / R$



55

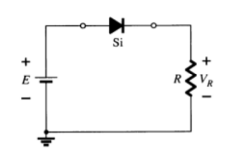
Series Diode Configurations

Reverse Bias

Diodes ideally behave as open circuits

Analysis

- $V_D = E$
- V_R = 0 V
- I_D = 0 A



56

Parallel Configurations

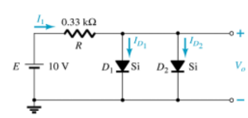
$V_D = 0.7\text{ V}$

$V_{D1} = V_{D2} = V_O = 0.7\text{ V}$

$V_R = 9.3\text{ V}$

$$I_R = \frac{E - V_D}{R} = \frac{10\text{ V} - .7\text{ V}}{.33\text{k}\Omega} = 28\text{ mA}$$

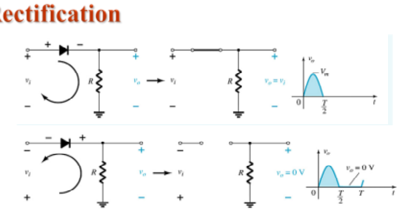
$$I_{D1} = I_{D2} = \frac{28\text{ mA}}{2} = 14\text{ mA}$$



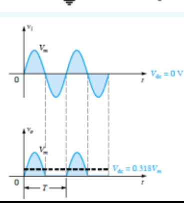
57

Half-Wave Rectification

The diode only conducts when it is forward biased, therefore only half of the AC cycle passes through the diode to the output.



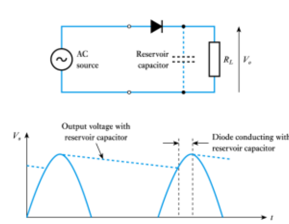
The DC output voltage is $0.318V_m$, where V_m = the peak AC voltage.



58

Half-Wave Rectification

Reservoir capacitor used to produce a steadier output.



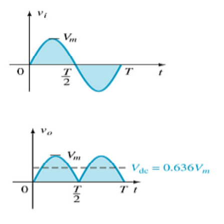
61

Full-Wave Rectification

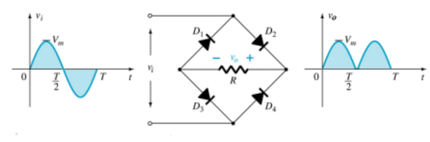
The rectification process can be improved by using a full-wave rectifier circuit.

Full-wave rectification produces a greater DC output:

- Half-wave: $V_{dc} = 0.318V_m$
- Full-wave: $V_{dc} = 0.636V_m$

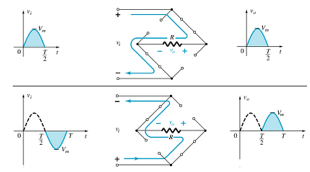


Full-Wave Rectification

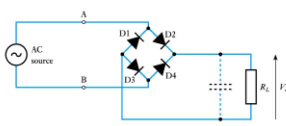


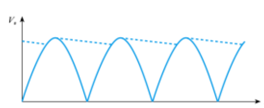
Bridge Rectifier

- Four diodes are connected in a bridge configuration
- $V_{DC} = 0.636V_m$



Full-Wave Rectification

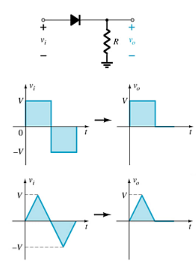




Diode Clippers

The diode in a series clipper "clips" any voltage that does not forward bias it:

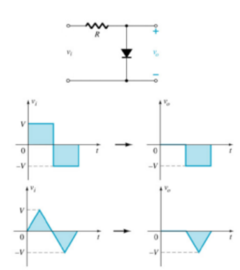
- A reverse-biasing polarity
- A forward-biasing polarity less than 0.7 V (for a silicon diode)



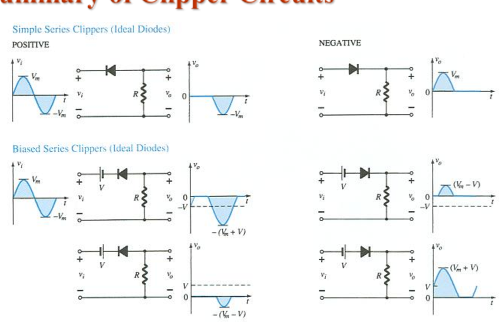
Parallel Clippers

The diode in a parallel clipper circuit "clips" any voltage that forward bias it.

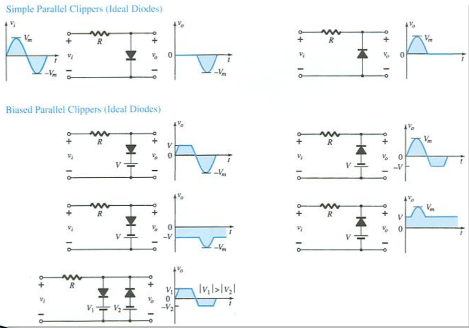
DC biasing can be added in series with the diode to change the clipping level.



Summary of Clipper Circuits

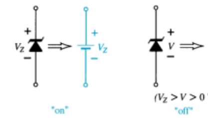


Summary of Clipper Circuits

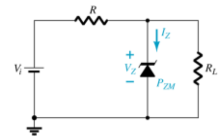


Zener Diodes

The Zener is a diode operated in reverse bias at the Zener Voltage (V_z).



- When $V_i \geq V_Z$
  - The Zener is on
  - Voltage across the Zener is V_Z
  - Zener current: $I_Z = I_R - I_{RL}$
  - The Zener Power: $P_Z = V_Z I_Z$
- When $V_i < V_Z$
  - The Zener is off
  - The Zener acts as an open circuit



Practical Applications

- Rectifier Circuits
  - Conversions of AC to DC for DC operated circuits
  - Battery Charging Circuits
- Simple Diode Circuits
  - Protective Circuits against
    - Overcurrent
    - Polarity Reversal
- Zener Circuits
  - Overvoltage Protection
  - Setting Reference Voltages